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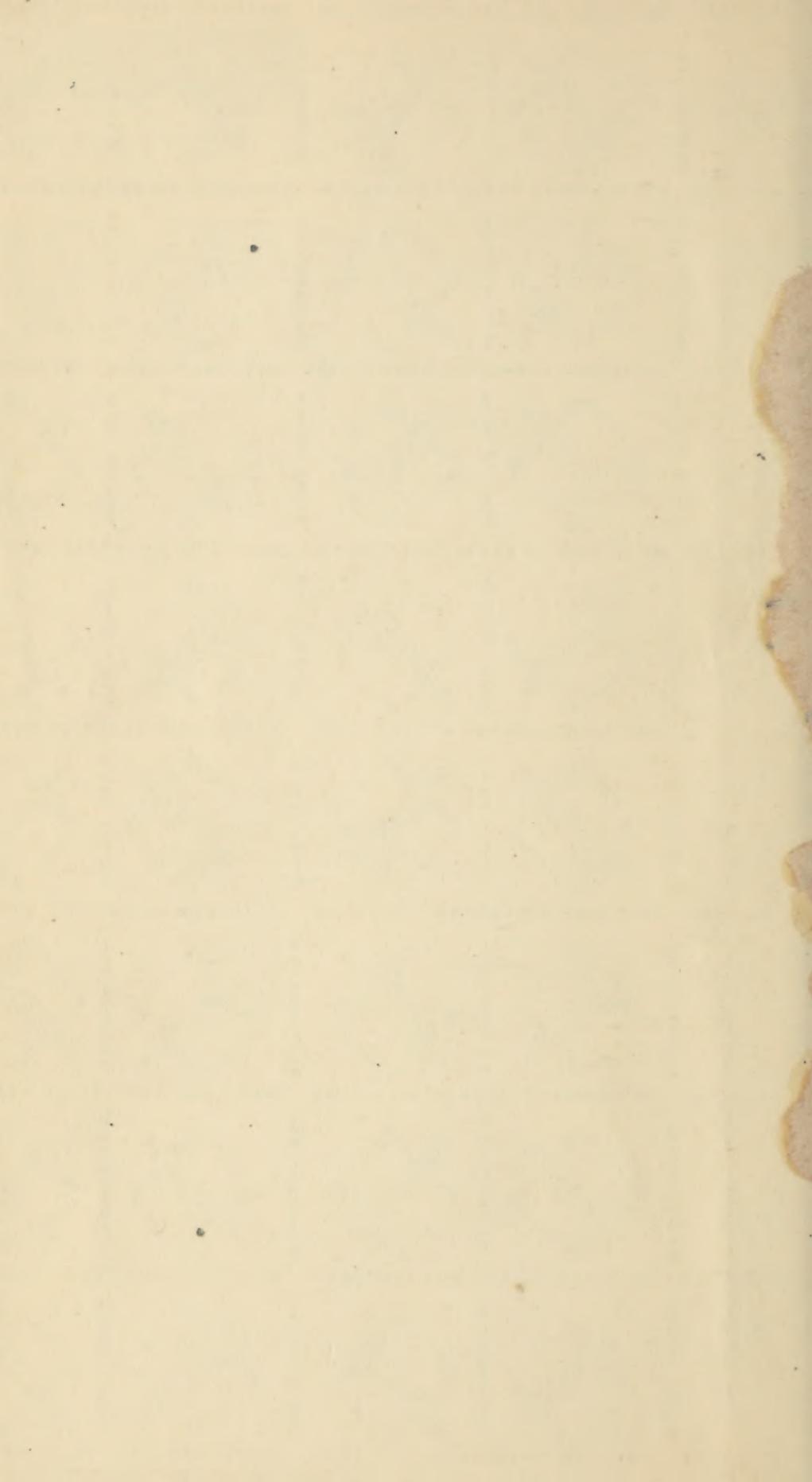
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ENTOMOLOGICAL FIELD HANDBOOK

U.S. Public Health Service OFFICE OF
MALARIA CONTROL IN WAR AREAS

ATLANTA, GEORGIA



FEDERAL SECURITY AGENCY
U.S. PUBLIC HEALTH SERVICE

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P R E F A C E

This is a preliminary draft of the entomological section of a Field Handbook for Malaria Control. It has been prepared by an entomologist with field experience in malaria control, who is now conducting the In-Service Training course. Guidance and suggestions have been freely given by the entomological staff of MCWA headquarters office.

It is hoped that by releasing this guide to our field personnel it will be subjected to critical field use and thereby improved through the suggestions and criticisms of its users. All suggestions for its improvement will be welcomed by those who are concerned with the preparation of the future field manual for malaria control.

M. D. Hollis
Senior Sanitary Engineer
Officer in Charge

Office of Malaria Control in War Areas
U. S. Public Health Service
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Atlanta, Georgia

INTRODUCTION

This manual is designed to aid MCWA personnel in carrying on the entomological phases of the program by presenting a summarized account of anopheline biology, methods used in handling mosquito specimens in the field, and procedures in gathering data for use by the control supervisor.

Since successful therapeutic or immunological measures for combating malaria have not yet been discovered, control of the mosquito vector must still be considered the most effective means for reducing the human malaria hazard.

Intelligent mosquito control work must be based on a knowledge of the varied habits of the specific anophelines responsible for malaria transmission. Therefore, a discussion of the general habits of mosquitoes is supplemented in this manual by more specific information on the habits of the anophelines of the United States. Although all twelve of the United States anophelines are capable of transmitting malaria experimentally, only three have been incriminated by epidemiological evidence as effective carriers of the disease under natural conditions. These are *Anopheles quadrimaculatus* in the Southeastern States, *A. albimanus* in the lower Rio Grande Valley of Texas, and *A. freeborni* in the Western States (page 29).

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GENERAL FACTS CONCERNING MOSQUITOES

Mosquitoes have four stages in their life cycle, the egg, the larva, the pupa, and the winged adult (page 4). Some species of mosquitoes lay their eggs on the water surface, others on moist ground near the water where the eggs subsequently will be flooded by rains or tides. The eggs may be laid either singly or in clusters called 'rafts'. The larval stage hatches from the egg and lives in the water. Although aquatic, the larva breathes air through a spiracular opening at the posterior end of the body which opens only when the larva is at the water surface. The bodies of all mosquito larvae have three distinct regions, (1) the head, (2) the thorax and (3) the abdomen (page 8). Mosquito larvae feed on minute plant and animal matter and grow rapidly. They undergo a series of four moults of the tough outer skin, at the last of which the pupal stage is produced. During the pupal stage no feeding takes place but changes occur within the body which form the adult mosquito. Mosquito pupae are aquatic and obtain air by means of breathing tubes located near the head. When fully formed the adult mosquito emerges from the pupal skin, rests for a few minutes on the water surface to dry its wings, and then flies away to feed and mate. After a few days the female is ready to deposit her eggs for the start of a new generation.

Adult mosquitoes are small, soft-bodied insects which are easily recognized by characteristic arrangements of the wing veins, the presence of scales on the wings, and the presence of a proboscis or beak. Sometimes mosquitoes are confused with crane flies and midges, which they resemble somewhat. However, close observation will show that these latter insects do not have scales or fringes on the wings and they seldom have long beaks.

Most mosquitoes have several generations each year. Some, such as the *Anopheles*, or malaria mosquitoes, usually breed in relatively permanent water and the number of generations is

largely governed by the temperature. Others breed in temporary rain pools and appear each time their breeding places are flooded. A few, such as some early spring *Aedes*, have only one generation each year.

Some mosquitoes bite at all hours of day or night. Some, such as *Anopheles*, are night biters while others, such as *Aedes aegypti*, bite only in daytime. Only female mosquitoes suck blood. Although the females of some species prefer the blood of man, many prefer that of other warm-blooded animals. Some prefer cold-blooded animals. Male mosquitoes do not suck blood but live on plant nectar, fermenting substances, etc.

POSITION OF MOSQUITO SUBFAMILY IN THE ZOOLOGICAL CLASSIFICATION

Kingdom: Animal - organisms usually having a sense of touch, and power of voluntary motion.

Phylum: Arthropoda - animals having an externally segmented skeleton, jointed legs and other appendages.

Class: Insecta, the insects - arthropods having three body divisions (head, thorax and abdomen), and three pairs of legs in adult stage. Most orders have two pairs of wings, although the mosquitoes belong to an order which has but one pair, the hind-wings being represented by a pair of clubbed appendages called halteres.

Order: Diptera, the flies - insects having one pair of wings and complete metamorphosis; i.e. the egg, larva, pupa and adult stages in the life cycle. The larvae are legless.

Family: Culicidae, the Culicids or mosquitoes - small soft-bodied flies having the characteristic mosquito appearance and wing venation. They include

two small subfamilies of non-biting mosquitoes (*Dixinae*, *Chaoborinae*) and the large subfamily of biting mosquitoes (subfamily *Culicinae*).

Subfamily: *Culicinae*, the true biting mosquitoes - insects having (a) a long proboscis (beak) projecting from the head, (b) scales present on the wing veins, and (c) a fringe of scales along the posterior margin of the wing.

DIVISION OF MOSQUITO SUBFAMILY INTO TRIBES, GENERA AND SPECIES

Mosquitoes belong to the family Culicidae, subfamily *Culicinae*, which is divided into five tribes, the *Anophelini*, *Culicini*, *Uranotaeniini*, *Megarhinini* and *Sabethini*. Each of these tribes is further divided into genera and each genus in turn into species. The naming of individual mosquitoes may be illustrated by the following example: The scientific name of the most important malaria mosquito in the United States is *Anopheles quadrimaculatus*. This name is obtained by combining the generic (genus) name, *Anopheles*, and the specific (species) name, *quadrimaculatus*. The name of the man who first described the species is placed after the specific name; for example, Thomas Say first described *quadrimaculatus*; thus the complete name of this mosquito is *Anopheles quadrimaculatus Say*. Most specific names are descriptive, e.g. *quadri* (four), *maculatus* (spot), referring to the four-spotted wings, but occasionally the original describer names the species in honor of a well-known worker, for example, *Anopheles barberi* Coquillett, *A. freeborni* Aitken, *A. bradleyi* King, *A. walkeri* Theobald, etc.

In the Southeastern States there are about 65 species of mosquitoes, ten of which are anophelines. On the Pacific Coast, 43 species are recorded, of which four are anophelines. A total of 12 anophelines occurs in the United States, two of which are common to both the southeastern

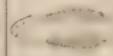
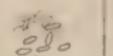
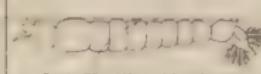
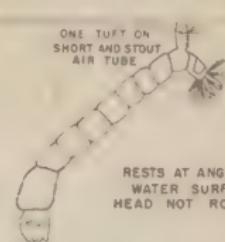
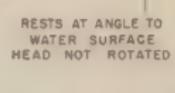
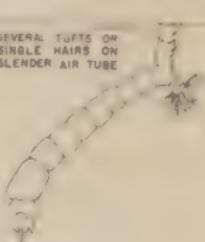
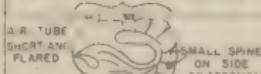
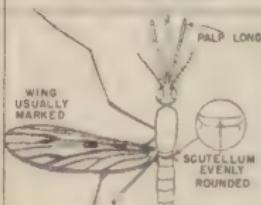
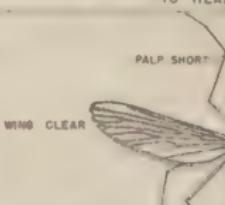
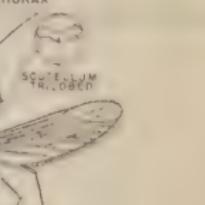
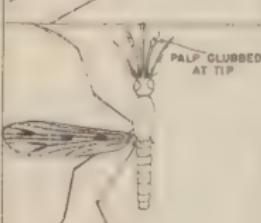
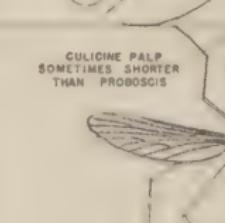
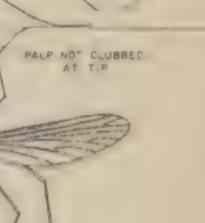
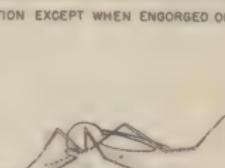
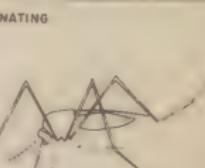
ANOPHELINES

CULICINES

ANOPHELES

AEDES

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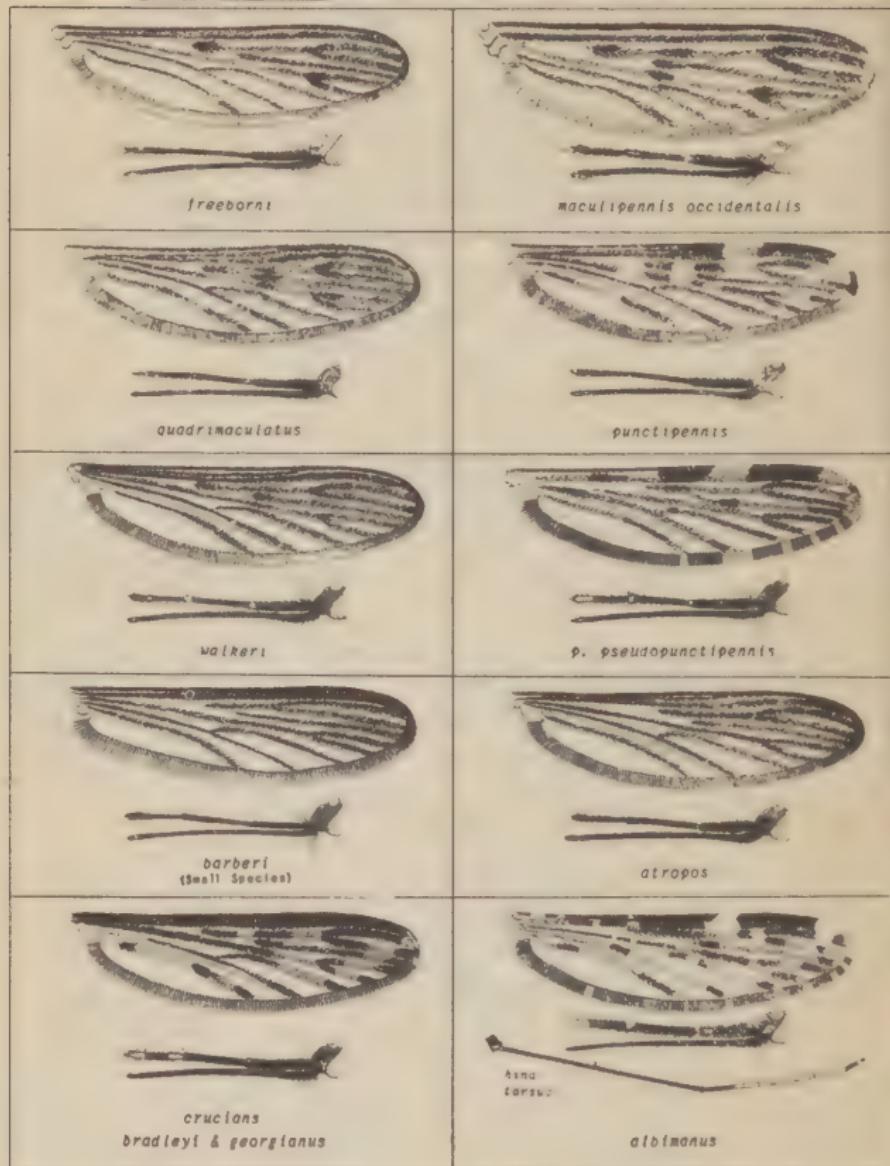
EGGS	 WITH FLOATS	 LAID SINGLY ON WATER	 NO FLOATS	 LAID SINGLY ON DRY SURFACE	 NO FLOATS	 LAID IN RAFTS ON WATER
	 PALMATE HAIR NO AIR TUBE		 ONE TUFT ON SHORT AND STOUT AIR TUBE	 RESTS AT ANGLE TO WATER SURFACE HEAD NOT ROTATED	 SEVERAL TUFTS OR SINGLE HAIRS ON SLENDER AIR TUBE	
LARVAE	RESTS PARALLEL TO WATER SURFACE HEAD ROTATED 180° WHEN FEEDING					
PUPAE	GREATER PROPORTION OF BODY CONTACTING WATER SURFACE  AIR TUBE SHORT AND FLARED SMALL SPINES ON SIDE OF ABDOMEN	AIR TUBE VARIABLE	 AIR TUBE LONG AND SLENDER	BASAL SEGMENTS OF ABDOMEN NOT CLOSELY APPRESSED TO HEAD AND THORAX	 SCUTELLUM TAILORED	
FEMALES	 PALP LONG WING USUALLY MARKED SCUTELLUM EVENLY ROUNDED		 PALP SHORT WING CLEAR ABDOMINAL TIP POINTED	 SCUTELLUM TAILORED ABDOMINAL TIP ROUNDED		
ADULTS	 PALP CLUBBED AT TIP		 CULICINE PALP SOMETIMES SHORTER THAN PROBOSCIS	 PALP NOT CLUBBED AT TIP		
		RESTING POSITION EXCEPT WHEN ENGORGED OR HIBERNATING				
						

DIFFERENTIATION OF MOSQUITOES INTO ANOPHELINES AND CULICINES

Malaria-carrying mosquitoes belong to the tribe Anophelini (which includes only the genus *Anopheles* in the United States), and in malaria work are usually referred to as anophelines. All other tribes of mosquitoes (non-anophelines) are often referred to as culicines. Anopheline and culicine mosquitoes are separated principally by the following characters (see also page 4):

	ANOPHELINES	CULICINES (broad sense)
Adult:	Palpi of both male and female long, in former clubbed at tip, in the latter about as long as proboscis. Posterior margin of scutellum evenly rounded. Wings of all but two species with definite color pattern, or 'spotted wings'.	Palpi of female much shorter than proboscis. Palpi of male long or short, but never clubbed at the tip. Scutellum posteriorly trilobed. Wings usually clear or without definite color pattern.
Egg:	More or less boat-shaped with lateral floats, laid singly.	Elongate, ellipsoidal or conical, without lateral floats, laid singly or in rafts.
Larva:	Horizontal position in the water just below the surface film, with which it maintains contact by palmate hairs and spiracles. Elongate air tube absent.	Maintains contact with the surface film only by the air tube, the body hangs obliquely or vertically downward. Air tube usually well developed and elongated.

WING AND MOUTH PARTS OF FEMALE ANOPHELES OF THE UNITED STATES



Illustrations (except *occidentalis*) from Ross & Roberts' Mosquito Atlas I,
courtesy American Entomological Society.

ANOPHELIINES

CULICINES (broad sense)

Pupa: Air tubes short and scoop-shaped, split down the front.

Air tubes broadly conical or elongate, tubular, unsplit.

IDENTIFICATION OF ANOPHELINE MOSQUITOES

ADULT

Adult anopheline identification in the field is essential for the malaria control worker. Furthermore, he must be able to identify them on sight when observed in their resting places. Page 6 shows the characteristics which most readily distinguish the species in the field, these being the wing pattern, palp marking, and color of the tarsus (foot). These markings, while typical in the illustrations, vary with the individual specimens and also vary with the different localities. For example, the four spots on the wing of *walkeri* may vary in intensity from the very dark spots of *freeborni* to very faint spots approaching typical *atropos*. Males generally resemble females in respect to these markings, although the wing markings are usually fainter. Positive identification of males is best based upon the structure of the terminalia (genital and anal parts). These studies involve delicate techniques of preparation which are not practical for the field worker or those without special training.

PUPA

Pupa (tumbler) identification is very difficult, and since this stage usually lasts no more than two or three days, pupae should be reared and the adults identified.

LARVA

Larval identification depends on certain minute characters and requires the use of the microscope. Consequently, in many instances, it is not practical to identify them in the field.

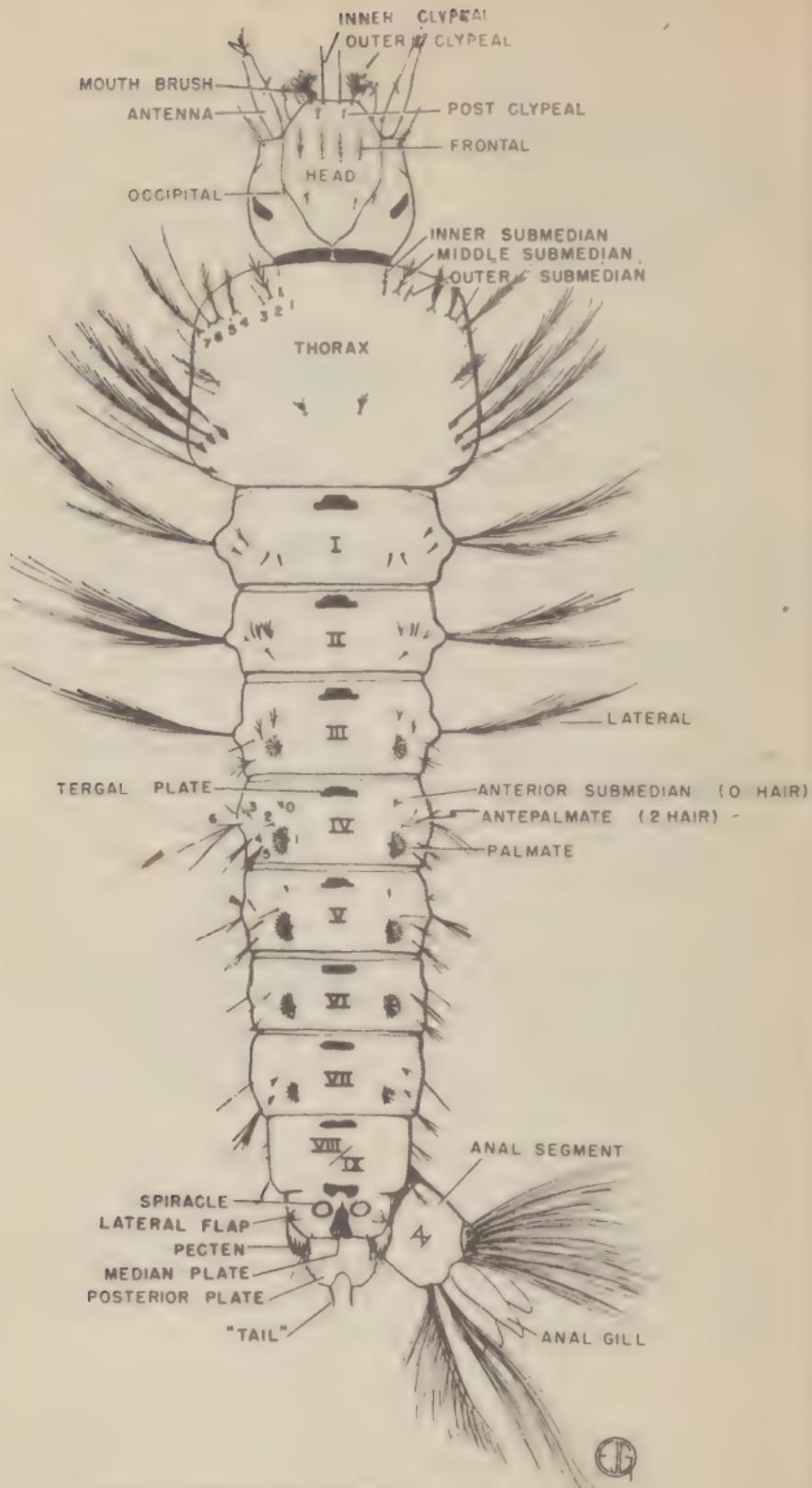


FIG. 15 DIAGRAM OF AN ANOPHELINE LARVA

or field office. Usually they are sent to a central office or laboratory for identification.

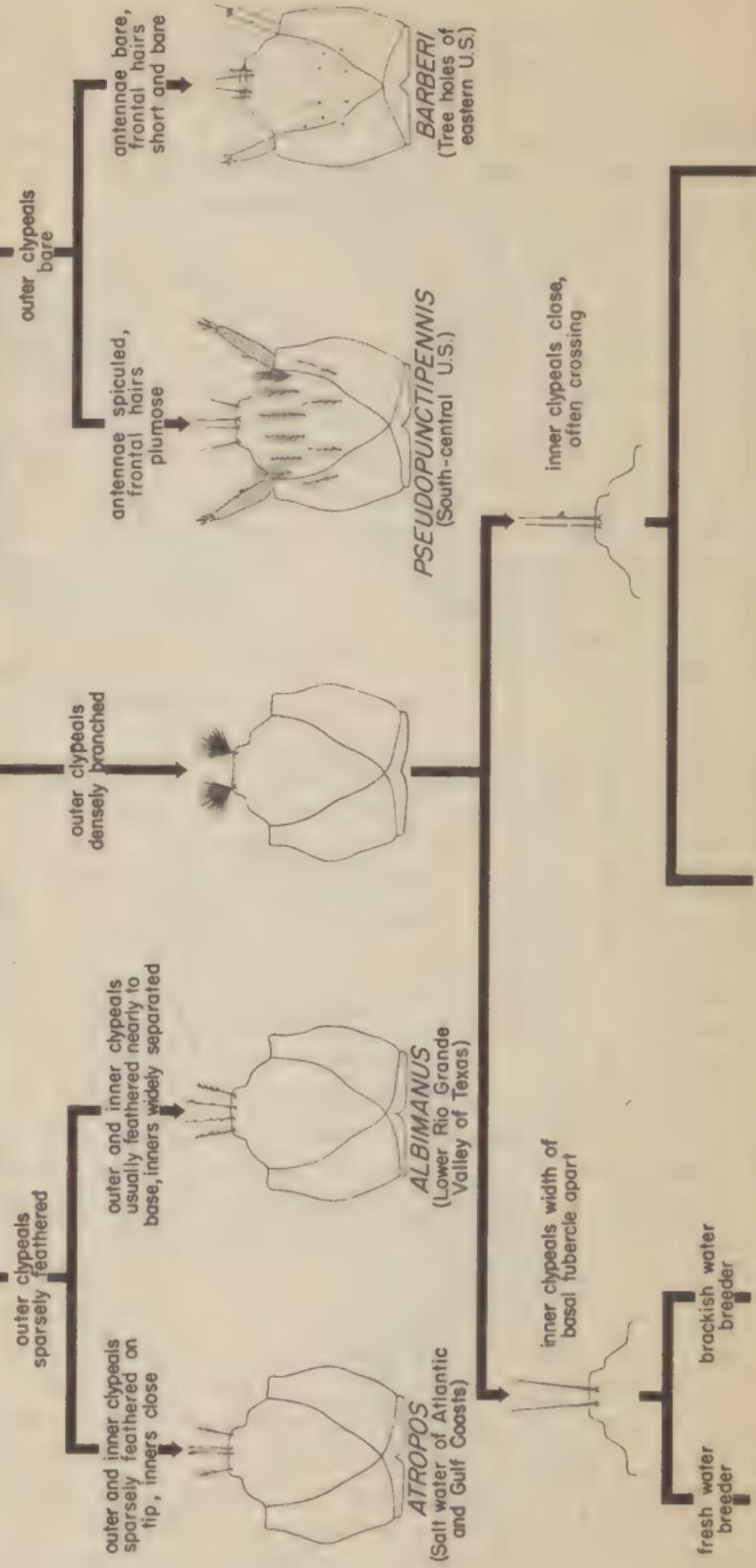
The pictorial key (pages 10 & 11) illustrates a method by which larval characters (page 9) may be used in identification. It applies only to fourth instar larvae. A knowledge of distribution and breeding habits will reduce the number of species to be considered.

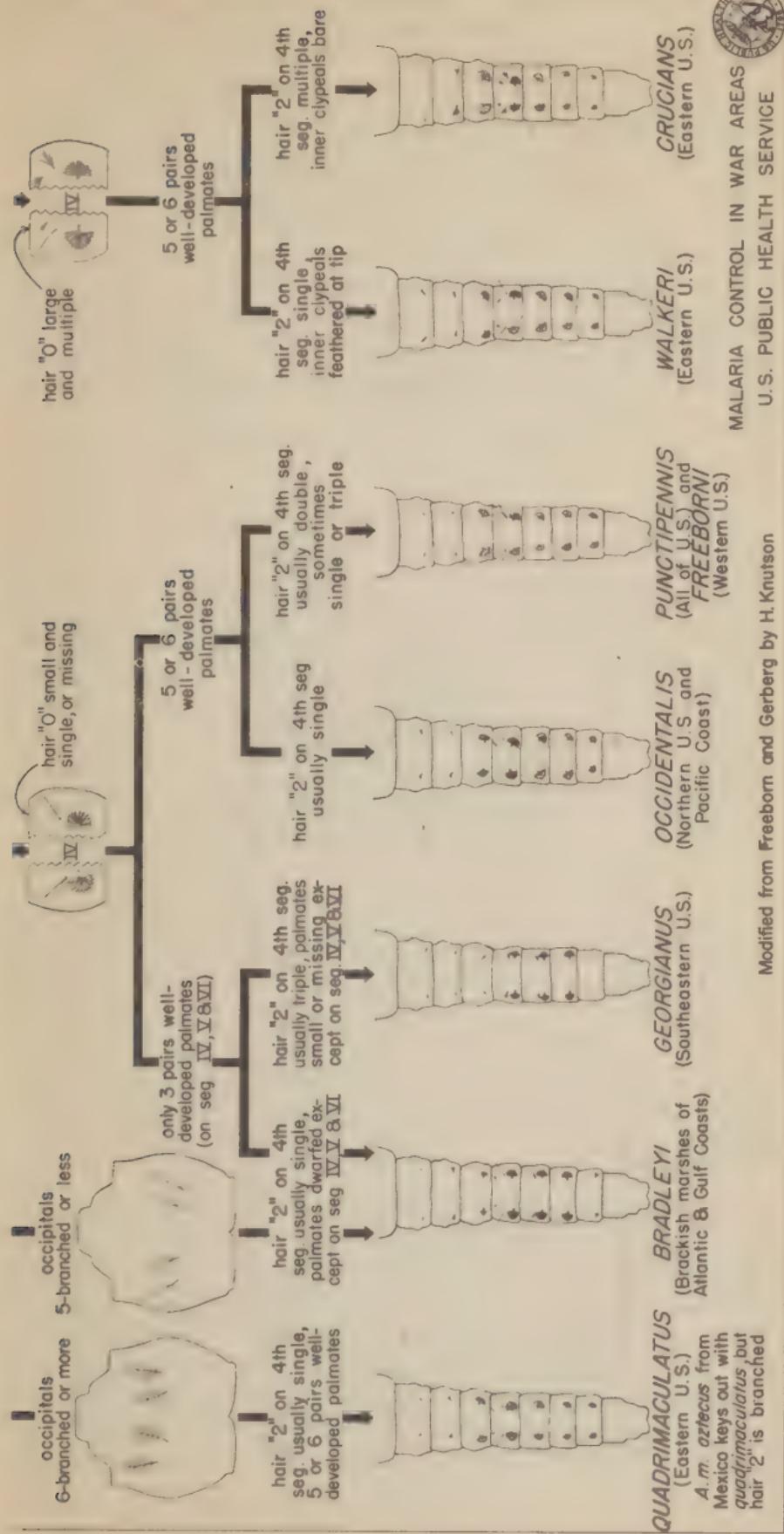
The first structure considered is the outer clypeals which will be sparsely feathered, densely branched, or bare. Inexperienced workers may confuse the mouth brushes with the outer clypeals although the mouth brushes are larger and silkier and will not appear in focus with them. If the outer clypeals are sparsely feathered, the specimen is *atropos* or *albimanus*, depending upon the extent of the feathering and the relative distance between the inner clypeals. If the outer clypeals are bare, the specimen is *pseudopunctipennis* or *barberi*, depending upon the nature of the antennae and frontal hairs.

Specimens with densely branched outer clypeals are studied in regard to the relative distance between the inner clypeals, which may be measured by a comparison with the width of the tubercle, a structure in which the inner clypeal is set. If the inner clypeals are more than the width of a tubercle apart and the specimen was taken in fresh water it is *quadrimaculatus*; if taken in brackish water it is probably *bradleyi*. If the salinity of the water in which it was collected is not known, *quadrimaculatus* may be distinguished by the more numerously branched occipital hairs and the presence of 5 or 6 pairs of well-developed palmates.

If the inner clypeals are less than a tubercle apart in width, the next step is to determine whether hair 'O' (anterior submedian) is small and single, or missing, or whether it is large and multiple. If hair 'O' is large and multiple, the specimen is either *walkeri* or *cruicians*, depending on whether or not hair '2' (antepalmate) is single or multiple and the inner clypeals are slightly feathered at the tip or

PICTORIAL KEY TO ANOPHELINE LARVAE OF UNITED STATES





bare. If, however, hair 'O' is small and single, or missing, the number of well-developed palmates must be considered. Five or six pairs of well-developed palmates indicate *occidentalis*, *punctipennis* or *freeborni*. Hair '2' on these three species is variable, but a consideration of geographical distribution may aid in determination. If there are but three pairs of well-developed palmates, the specimen is either *bradleyi* or *georgianus*. *Bradleyi* breeds in brackish water (in contrast to fresh water), usually has hair '2' single on the fourth abdominal segment (instead of triple), and the remaining palmates are less reduced in size.

EGG

Since eggs are relatively difficult to find in the field, there is little need for the field worker to attempt their identification although minute differences in their structure can be noted by close microscopic examination.

LIFE HISTORY AND HABITS OF THE UNITED STATES ANOPHELINE SPECIES

Anophelines breed in a wide variety of aquatic situations, and breeding waters may be classified on the basis of various environmental factors. In this country, however, it has been found advisable in practical control work to determine breeding areas by identifying the larvae found in continuous intensive searching of all likely waters.

The eggs of anophelines are laid singly on the water surface. The larvae or wrigglers appear as mere 'slivers' on the water, and move about at the surface by a series of quick jerks. Breeding is continuous throughout the summer months and the number of generations varies with the length of the summer season and the temperature. In the Northeastern States it may vary from 2 to 3 generations, while 8 or 10 may occur along the

Gulf of Mexico. Here breeding at a reduced rate may proceed even during the winter.

Adult anophelines rest with the body at an angle (page 4) to the resting plane. This is in contrast to the culicines which hold the body more or less parallel to the resting surface. The angle of the abdomen of engorged female anophelines when at rest is reduced due to the added weight of the blood meal and sometimes approaches that of the culicines. During hibernation the resting position of anophelines also approaches the culicine stance.

Anopheles quadrimaculatus

This important malaria vector of the South-eastern States (page 29) prefers open sunlit or partially shaded areas in which to oviposit. It occurs predominantly in fresh, clear, quiet, neutral or alkaline ponds of a permanent nature which contain an abundance of protective vegetation or floating matter. Permanent grassy swamps, rice fields, borrow pits, lake margins, ponds and pools may produce hordes of *quadrimaculatus*. The larvae may sometimes be found in less typical places such as old tin containers, the mouths of caves, rock pools, etc. This may be due to intensive control measures which eliminate its preferred breeding places. The larvae feed on a great variety of small organisms and will ingest particles of any material present on the water surface provided they are small enough.

The adults are active principally at night although on cloudy days or in shady locations the female may occasionally bite during the day. Flight and dispersion begin at dusk and continue about an hour or so. During the remainder of the night, flight is probably limited to local forays in search of blood meals. Another period of activity begins just at daylight and ends with a general shift to daytime resting places. Adults rest during the day in such haunts as barns, privies and other outhouses, hollow trees, tree holes, culverts, chimneys, boxes, under bridges,

or in other places which are dark, still, damp and cool (pages 24 & 25). They are frequently found hanging from spider webs in these resting places. The resting angle of *A. quadrimaculatus* is approximately 45°. The numbers found in such places give a reliable index of their density in the surrounding area and therefore regular inspections, usually at weekly intervals, provide a means of gauging the effectiveness of control work in decreasing the adult anopheline population. The presence of a high percentage of males in a resting place usually indicates that breeding is taking place close by, since males usually fly only short distances from their breeding places.

Light traps may be used to measure the abundance of *quadrimaculatus* and, when operated continuously throughout the active season, they provide a general over-all picture of the fluctuation of adult densities. Animal traps also may be used for this purpose. However, the use of these methods is more time-consuming than the use of natural resting places.

The effective flight range of *quadrimaculatus* is generally considered to be about a mile and therefore control is usually limited to the area within one mile of the place being protected. This species enters houses freely and bites indoors, a characteristic that is doubtless responsible for its importance as a malaria vector. Its feeding is not, however, limited to man.

Since temperature, geographic location and other factors influence the length of the various life history stages, no definite periods of time for each stage can be given. Under optimum conditions of food, temperature and humidity, about 14 or 15 days are required for the complete life cycle. This period is roughly divided as follows: egg, 2 or 3 days; larva, 1 week; pupa, 2½ to 3 days, and preoviposition period of adult (from emergence to first egg laying), about 4 days. When the food supply is scanty, or temperatures low, the period for development may be greatly prolonged.

In the northern and central portions of its range, the *A. quadrimaculatus* female hibernates in dark, damp, still places where the temperature remains uniformly cool. Such places are caves, large hollow logs and trees, cellars, basements, etc. Overwintering females oviposit in the spring and each successive generation increases in numbers if breeding conditions remain favorable. The population peak is attained during late summer and is followed by a rapid decline. In the southern portions of its range, breeding may be more or less continuous, with short dormant periods during colder weather.

Anopheles freeborni

This is the principal malaria vector in western United States (page 29). It breeds primarily in small, insignificant pools of comparatively fresh water which are at least partially exposed to sunlight, and contain vegetative protection and floatage. Hoofprints in seepage areas, bays in streams, cut-off pools, roadside pools of semi-permanent nature resulting from careless irrigation, irrigation canals and ditches, drainage ditches, old rice fields and countless other similar areas are typical breeding places. It is rarely found in foul water, artificial containers, or large bodies of water such as ponds (in contrast to *quadrimaculatus*), clean-banked borrow pits or extensive swamps, in deep water or heavily wooded areas.

A. freeborni is associated with semi-arid regions and its seasonal history and habits are governed by the available breeding water. In California heavy rains occur from November to April or May which greatly increase the available number of suitable breeding areas. The dry season occurs from May to late October and suitable natural breeding places decrease in number and extend until November. In late fall (October) females from the last generation disperse from the restricted breeding foci to resting places in the vicinity of the widely scattered wet-weather breeding areas where they enter a condition of semi-hibernation, although they become

active and bite during warm periods. In February they take to the wing, bite voraciously and lay eggs for the first spring generation. This first oviposition (and resulting generation) is wide-spread because of the increased number of water areas caused by the heavy winter rains and the paucity of predators. The succeeding generations, of which about six occur in central California, would be gradually reduced in their range and size by the recession of available breeding places if it were not for the presence of irrigation water which, in some areas, compensates for the lack of summer rains and maintains heavy densities of the species in areas that would otherwise be dry.

The dispersal flights of this species often necessitate a control zone of more than one mile. This is true especially if the densities are high. Periodic local observations of densities and flights are necessary to determine the size of the protective zone. Counts in natural resting places are reliable indices of adult densities. Adult counts during late June, July and August are normally low as compared to the peaks in early June and particularly September.

A. freeborni larvae can not be separated from those of *A. punctipennis*, and for positive identification adults must be reared. However, larvae can be determined with some degree of reliability by noting the type of water from which they are collected. *Punctipennis* prefers stream margins and deeper pools in contrast to the situation given above. Within their range adult *freeborni* may be confused with *A. occidentalis*. However, specimens of the latter, if not rubbed or damaged, can be distinguished by the whitish, yellowish, or copper-colored wing tip.

Anopheles albimanus

This tropical species is the most important carrier of malaria in the Caribbean region, but is found in this country only in the lower Rio Grande Valley of Texas (page 29). It is a much more general breeder than *quadrimaculatus*,

being found in permanent or semi-permanent pools, swamps, marshes, ponds, or lakes of brackish or fresh water. An abundance of vegetation or floating debris is necessary for its existence in large bodies of water. Large numbers of larvae may also be found in ground pools such as hoof prints, wheel ruts, seepages, ditches, and even artificial containers, especially if they contain algae. Larvae are most commonly found in full sunlight.

A. albimanus flight range is ordinarily limited to about 2 miles, but occasionally a 2½ or 3 mile protective zone must be established around an area to obtain control.

Natural resting places such as those used to obtain *quadrimaculatus* adult indices can be used for measuring densities of this species in the lower Rio Grande Valley. However, in Puerto Rico *albimanus* does not frequent such places in the daytime and animal baited traps are principally used for this purpose. *Albimanus* is readily attracted to light traps, and recent studies in Puerto Rico have shown that light traps may indicate fluctuations in anopheline population more reliably than do the animal bait traps.

Anopheles crucians

This species is closely allied to *bradleyi* and *georgianus*, and the adult females of the three have not been distinguished. *A. crucians* is a common species in the low coastal plains of the Southeastern States, but otherwise it is limited in abundance within its range, which in the United States extends up the Atlantic Coast to Massachusetts and westward into southern Illinois, central Oklahoma and Texas. It has also been taken in the Pecos Valley of New Mexico. *A. crucians* breeds in swamp pools, usually partly shaded, and prefers slightly acid waters. The larvae may often be found in the center of clumps of vegetation where they are difficult to collect with a dipper.

Although susceptible to infection with

malaria parasites, it has rarely been found infected in nature and is not known to be of importance in malaria transmission.

A. crucians frequents the same types of natural resting places as does *quadrimaculatus*. It is attracted to light traps, apparently more so than *quadrimaculatus*. When resting it can be distinguished from the latter by the angle of the body which approaches 90° to the resting surface.

Anopheles bradleyi

This species is found only in brackish water along the Atlantic and Gulf coasts from Maryland to Vera Cruz, Mexico. Water of low salt concentration is preferred. Habitats recorded include salt marsh pools containing floatage, algae, and grasses. Little is known concerning the adult habits, which probably are similar to those of *crucians*.

Anopheles georgianus

This species occurs locally in the South-eastern States as far west as eastern Texas. It breeds in fresh water pools, hoof prints, and other depressions in soggy, mucky or seepage areas. *Georgianus* larvae are said to be slow in rising to the water surface when collected in a dipper. It may occur with *crucians* in large pools. It is believed to pass the winter in the larval stage. Little is known concerning the habits of the adults, but they are believed to be similar to those of *crucians*.

Anopheles punctipennis

This species ranges throughout most of the breadth of the United States from the Atlantic to the Pacific. It is our most widely distributed anopheline, and is found in all except the more arid regions. It breeds in a wide variety of habitats, but appears partial to the grassy edges of deep slow-flowing streams. It prefers cooler water than does *A. quadrimaculatus*. This is believed to explain its occurrence in greater

numbers in the spring and fall in its southern range. Farther north a more nearly even seasonal population is encountered.

The natural resting places of *punctipennis* are the same as those of *quadrimaculatus*. Culverts and bridges are said to be especially attractive to them. *A. punctipennis* also is readily attracted to light traps. When at rest, the axis of the body and beak is almost perpendicular to the surface, and in this respect closely resembles *crucians*.

Although it is readily infected with malaria parasites in the laboratory, it does not feed to any great extent on man and seldom enters human habitations. Epidemiological evidence indicates that it is not an important malaria vector.

Anopheles pseudopunctipennis

In the United States, this species ranges along the Pacific coast south of Oregon and in the arid southwest. It is primarily a receding stream breeder. It is found as far south as Argentina in South America, making it the most widely distributed species in the Western Hemisphere.

The larvae require a great deal of sunlight for their development, and the preferred breeding places are pools and eddies in shallow or drying streams, especially those containing mats of green algae. Other recorded breeding places are seepages, especially those in dry beds of subterranean streams, ground pools, and even artificial water containers such as fountains or tanks.

The habits of the adults of this species apparently vary throughout its range. In some areas it is recorded as entering homes readily and attacking man while in others it feeds principally on animals. It is not considered to be of malarial importance in the United States, but in certain regions south of the United States it is an important malaria carrier.

Anopheles occidentalis

In the United States this species occurs in a narrow coastal strip along the Pacific Coast of the upper two-thirds of California, in Oregon and Washington, and eastward in the first one or two tiers of States bordering Canada. Although malaria recently has been transmitted experimentally by this species its northern distribution excludes it as an important vector of malaria.

Adults of *occidentalis* have been found in association with both *quadrimaculatus* and *punctipennis* in the northeastern United States in old barns, cabins, privies, and nail kegs. Biting has been recorded in the bright sunlight in early spring, with vigorous biting in the evening.

Anopheles atropos

The typical adult female has almost clear wings and very faintly ringed palps. However, specimens are occasionally encountered which have well marked wings and an almost complete absence of white scales on the palps.

A. atropos is a salt water species and breeds in the coastal marshes from New Jersey to Texas. Larvae are commonly taken in brackish pools and in shallow mucky water marshes where the water ranges from 3 to 12 percent sea water. It is sometimes taken with *bradleyi*, but the latter generally is found in water of lower salt content.

A. atropos is a severe biter, both by day and by night, and readily enters dwellings. Although it is easily infected with malaria parasites, its importance as a vector is doubtful.

It comes readily to lights. The resting angle assumed is considerably more acute than that of *quadrimaculatus*, the abdomen more nearly approaching parallelism with the resting surface.

Anopheles walkeri

In the United States, *walkeri* occurs locally

in the area extending from the Atlantic Coast to the Great Plains. Formerly it was considered rare, but during the past few years it has been recorded locally numerous throughout its range. These recent recordings may be the result of former confusion with *quadrimaculatus* or other anophelines, or to a recent upswing of populations, or both. In addition to the palps banded with white, the wing spots are usually less distinct than in *quadrimaculatus*.

It is most commonly encountered breeding in sunny marshes or along lake margins among thick growths of aquatic vegetation. It may also occur along the grassy edges of slow-flowing swamp streams and bordering pools.

It most commonly bites man in the evening and at night, but will also bite occasionally in bright sunlight. Adults prefer to rest on the emergent vegetation of their breeding places and few instances of collections in resting places are recorded. They come readily to lights. The angle assumed while resting is comparable to that of *atropos*.

Anopheles barberi

This very small, rare species occurs locally in the eastern United States as far west as Missouri and Texas. The larvae usually are taken in tree holes, but sometimes occur in barrels and other artificial receptacles.

It will enter dwellings and bite severely. Although it has been experimentally infected with malaria parasites, it is not considered an important vector because of its rarity.

Occasionally *barberi* is taken in light traps. Adults are most commonly collected in tree holes, resting above the water from which they emerged, but are sometimes taken in sheds, barns, etc. The resting stance approximates that of culicines, and it is doubtless often overlooked as the latter, which frequently causes it to be included in culicine collections.

ENTOMOLOGICAL PHASES OF MALARIA CONTROL

In preparing for malaria mosquito control work in an area that is known to be or is epidemiologically suspected of being malarious, it is important that the local anopheline fauna and relative abundance of the various species be determined. If the vector species is unknown for the area it must be ascertained, and its breeding areas located. With this information available it is possible to prepare a comprehensive plan for an efficient malaria mosquito control program. After the control program is initiated, entomological data are utilized as a routine guide for current control operations.

DETERMINATION OF THE LOCAL ANOPHELINE FAUNA

Determination of the fauna and the relative abundance of the various species is accomplished by finding the numbers present in a series of resting places, by the use of bait or light traps and by records of biting or a combination of these methods.

Daytime resting places

Adult resting places for anophelines consist of such haunts as barns, privies, culverts, hollow trees, and the like where cool, dark, and quiet conditions exist (page 24). The number of resting adults in several of these places in an area gives a reliable index to the population density. In determining the number of anophelines present in one of these stations the inspector may collect all, or if large numbers are present, he may collect approximately 25 and then estimate the total number remaining in the resting place. Inexperienced men should count and then collect all of the mosquitoes. The usual method of collecting is to place a chloroform tube over each individual specimen which has been located by means of a flashlight. However, an aspirator may be used sometimes instead of the killing tube (page 31). If the specimens are not identified on the spot they are placed in a small pillbox with a wisp of cotton, and stored for future reference.

Each pillbox must be labeled with pencil giving the exact location, date and collector's name. Since adult resting places vary in size and type it is not possible to make an accurate comparison of the density of one area with another. However, regular counts in these stations indicate fluctuations in density at that place. Natural resting places examined should be sufficiently close together to indicate conditions over the entire area concerned.

"Artificial resting places

Boxes or kegs or small privy-like buildings may be used when an adequate number of good natural resting places cannot be found. To be attractive to anophelines these artificial shelters should approximate conditions in the natural resting place. They must be adequately shaded so as to be dark, moist and cool inside. Trial and error is necessary to properly locate artificial resting places and the usual practice is to place several in the same locality and after repeated inspections to remove all except the one that proved most attractive to anophelines.

Mosquito traps

The New Jersey type of light trap (page 39) is also used to supplement data concerning the prevalence of anophelines and is especially valuable in indicating the relative abundance of non-anopheline mosquitoes. Although *Anopheles quadrimaculatus* and some other anophelines are not attracted to lights in large numbers the light trap is useful in securing supplemental data, especially where there are no natural or artificial resting places available in a portion of the area. It has recently been shown that light traps are particularly efficient for measuring *albimanus* densities in Puerto Rico. For best results these traps should be located at least 30 or 40 feet from buildings in small open areas near trees and shrubs. They should be elevated 5 or 6 feet from the ground in areas that are free of smoke and gases. A 25-watt bulb is the usual light source and each trap should



UNDER BRIDGE



CAVE
COURTESY T.V.A.



NAIL KEG



TARGET PIT



BARN



BARN



BOX

SOME TYPICAL ADULT



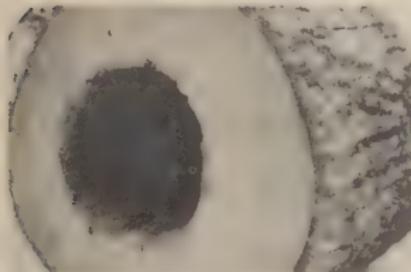
HOUSE



CLOSE-UP OF MOSQUITOES RESTING



UNDER BRIDGE



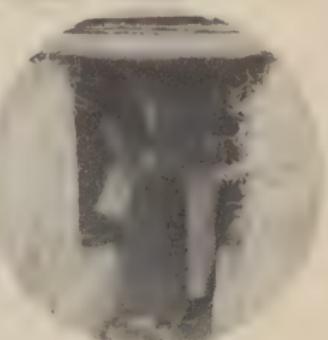
HOLLOW LOG



CHICKEN HOUSE



SHED



CULVERT

MOSQUITO RESTING PLACES

be placed so that other lights will not compete with it. It has been found that the most reliable data on the abundance of anophelines can be secured from these traps when they are operated 5 nights a week. When the trap cannot be operated personally, arrangements can usually be made with some interested individual who will assume responsibility for operating the trap and removing the collections once a day. The mosquitoes removed from the trap each morning should be placed in a pillbox on which is written such data as the location, date and collector.

Animal bait traps

These traps have been used successfully in Puerto Rico for estimating the densities of *A. albimanus* since this species does not rest in barns and similar places during the day. These traps are small roofed cages that are mosquito tight except for a horizontal V-shaped slot in each side through which mosquitoes may enter, but not escape. Mosquitoes are attracted by a bait animal placed in the building.

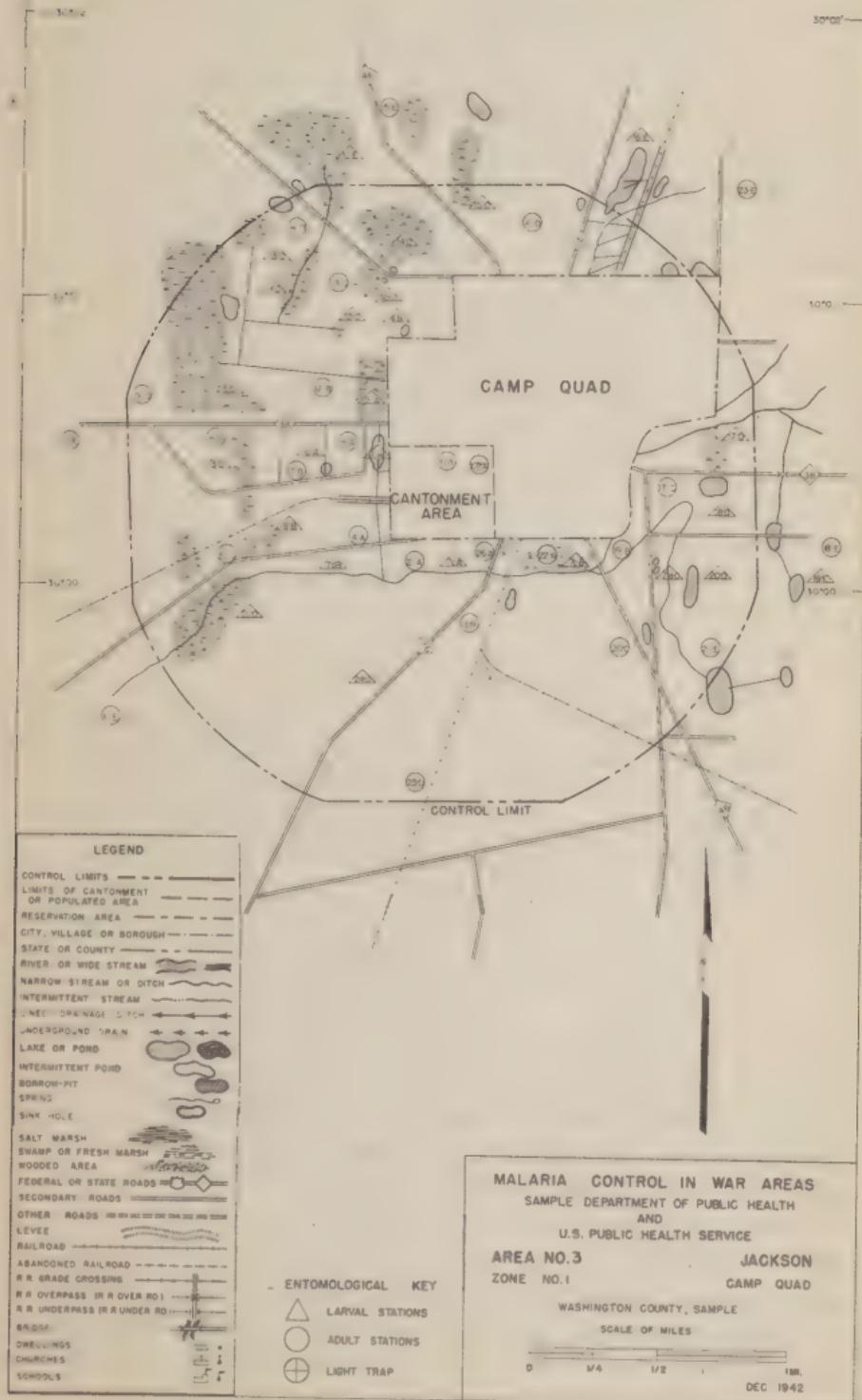
Biting records

Such records are made by capturing the anophelines which alight on the bared arms and legs of the collector. These records must be made when anophelines are active and a flashlight is necessary to locate the mosquitoes. Such collections should be for a standard period of time, such as 15 minutes. This method is not recommended in areas where malaria is prevalent.

Collecting stations

Collecting stations (page 27) should be spotted on the map by means of numbers to facilitate making and interpreting mosquito records. Each station number is followed by a letter indicating its distance from the place where protection is desired. One method used is as follows: 'A' stations are those inside or within 1/4 mile of the protected population; 'B', 1/4 to 1/2 mile; 'C', 1/2 to 3/4 mile; 'D', 3/4

SCHEMATIC MAP
SHOWING
ENTOMOLOGICAL INDEX STATIONS



to 1 mile; and 'E' outside of the control limits. Preferably, 'E' stations should be 1/2 mile or more beyond the control limits. In case the controlled area is extended beyond a mile the area beyond one mile and still inside the controlled area is named 'D'.

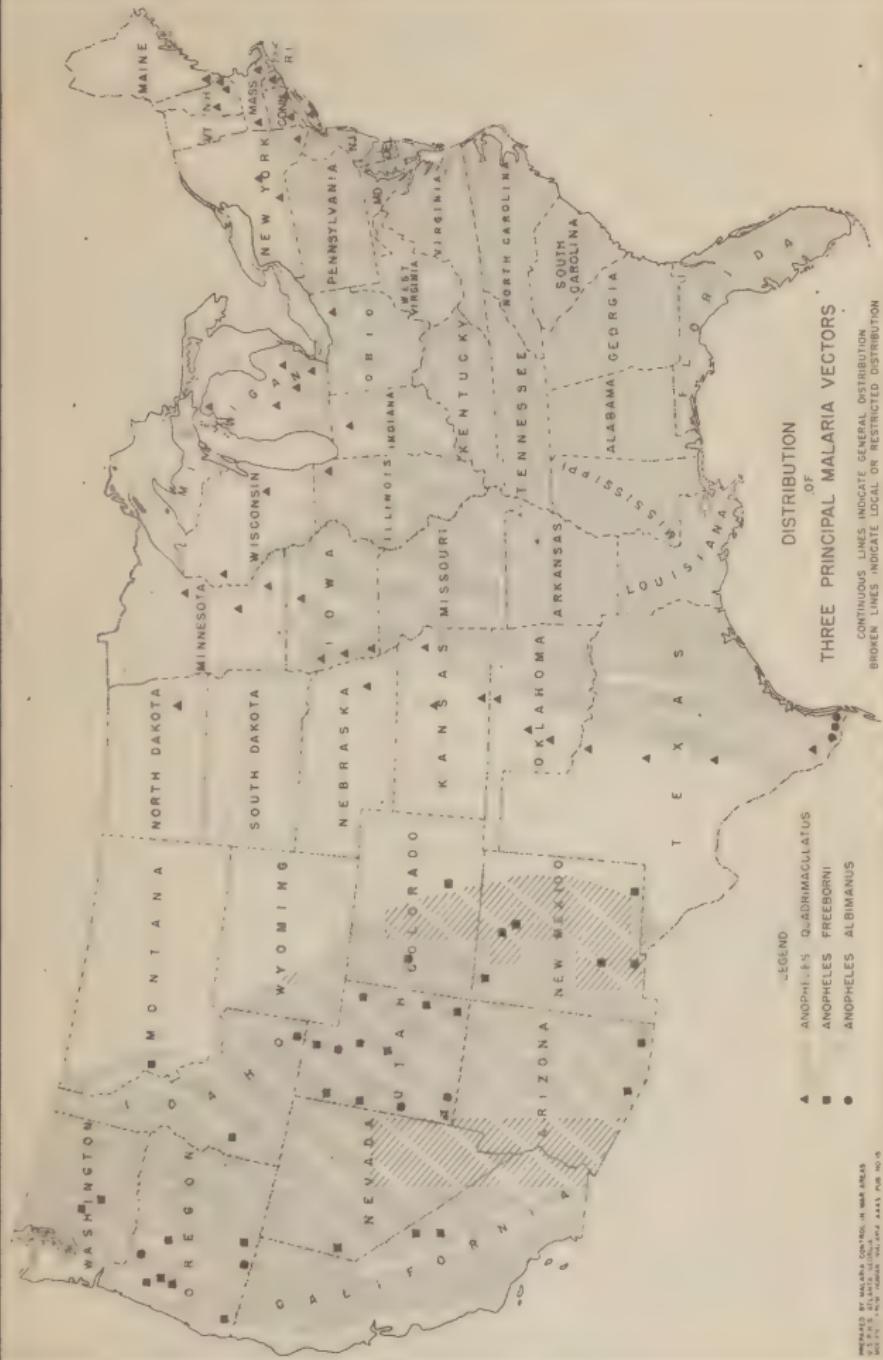
The 'E' stations should be established where breeding conditions are comparable to those within the control limits. These stations should indicate the potential anopheline density to be expected near the protected activity if no control measures had been undertaken. Thus, 'E' stations that are comparable to those within the control zone measure the accomplishment of the control work in reducing malaria vectors.

The number of adult stations necessary for an accurate evaluation of mosquito densities varies with the size of the area concerned. Adult 'A' stations should be approximately 1/2 mile apart when possible. However, even a small control zone should have at least 5 or 6 'A' stations. Fewer stations are necessary at greater distances from the protected activity but there should be at least two B, C, D, and E stations for each zone.

Collecting stations should not be changed because each change interrupts the continuity of data. However, if it becomes necessary to discontinue a station, its number should be discontinued also and the replacement station given a new number.

Determining the malaria vector

This involves dissection of the various species to find the malaria infection in the mosquito. This technical work is logically a job for a parasitologist, if one is available, and the work of the entomologist in this connection may consist only of obtaining the necessary specimens and field data. It often has been found that even though more than one easily infected anopheline is present, only one is the important vector in the area. In the United States only



three of the twelve anophelines are incriminated as important malaria vectors. These are *Anopheles quadrimaculatus*, in the Southeastern States; *A. albimanus* in the lower Rio Grande Valley of Texas; and *A. freeborni* in the western States (page 29).

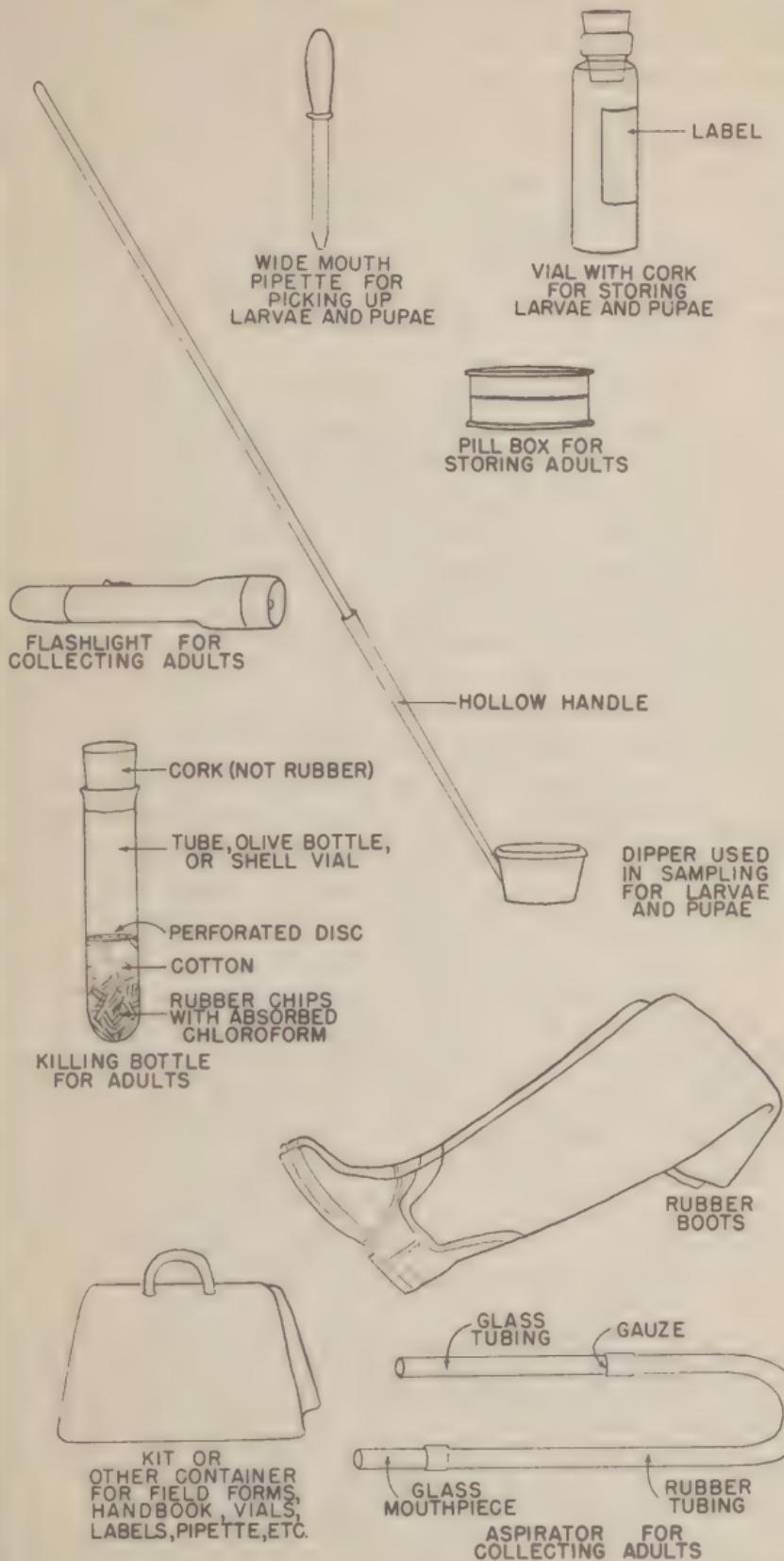
Accurate location of breeding places

This is most important for malaria mosquito control work. The best available map should be secured and a reconnaissance of the area made to locate as far as possible all waters within vector flight distance of the population to be protected.

All water areas not already shown on the best map available should be added and all possible breeding places searched for occurrence of vector larvae. In searching for mosquito larvae a pint dipper with a long handle is commonly used. Dips should be taken of the water surface in various areas throughout the body of water, making sure that the dipper is not filled so full that it overflows. The water should not be scooped up vigorously but the dipper should be pressed gently down, and the surface water allowed to flow into it from the side, bringing the dipper to a horizontal position again while doing so. Larvae can also be collected by skimming the water surface with the dipper. Nearly all dips should be taken in and around floating debris and vegetation as the great majority of larvae and pupae will occur there rather than in open water. Often larvae will be found adjacent to the edge of a mud bank, from which it is difficult to dislodge them.

The number of dips will depend upon the size and nature of the breeding area, but dips should be in multiples of ten in order to permit the uniform summarization of records. Usually ten dips are sufficient for a very small pool, while a large breeding area, such as a rice field or large swamp, may require several hundred dips distributed throughout the various habitats. Fewer dips are necessary to adequately sample a place where anopheline larvae are readily found

DAILY FIELD EQUIPMENT



than where few or none are found. The number of dips will be further determined by the various types of shoreline, vegetation, and other conditions which determine various habitats. Some larvae, after being dipped up, may stay below the water surface for some time, hiding under debris in the dipper. Larvae and pupae are drawn up with a small quantity of water by means of a wide-mouthed pipette and transferred to a vial or other container. The collections of each station are placed in a separate vial, adequately labeled.

Larvae and pupae sometimes will continue to live and mature even when a pool appears to be little more than mud. In these cases dippers are of little value unless the muddy water is scooped up and the mud allowed to slowly settle out. Careful observation of the surface of a muddy pool often results in their detection, and they may be transferred directly from the pool to the vial by a pipette. This latter operation often is best accomplished if the muddy water is stirred up, the larvae being detected against the muddy background as they come to the surface. In swamps where water is shallow and choked with grass, the vegetation may be pressed down with the feet, and the larvae and pupae recovered as they return to the surface.

Large larvae and pupae are placed in water in small vials for future identification. These vials should be labeled to show the exact location of the collection, the date, and the collector's name. Some methods of rearing larvae and pupae to adults for identification are illustrated on page 42. If the larvae are to be preserved for identification, they should be placed in 50-70% alcohol or 4-5% formalin.

All possible anopheline breeding places in the control zone should be indicated on the area map and numbered in the same manner as adult stations. Very large bodies of water or long streams may be given separate station numbers according to their different habitats or sectors, or may be given only one station number

and the various collecting places designated as substations by means of small letters. When small breeding places occur in a circumscribed area they need not be given individual numbers but may be grouped and substations designated if necessary.

Plans for entomological work on a malaria-mosquito control program

The information secured in the entomological survey serves as a basis for the control program.

In the endemic malarious areas, the presence of only moderate numbers of malaria vectors near populations to be protected is considered justification for active mosquito control measures. In such cases an 'inspection and control' project is planned involving continuous inspection and control throughout the season. Such projects are also desirable outside the endemic malarious region in areas where the vector is present in large numbers and human malaria-carriers are present, a condition of increasing importance because of migrating workers and returning troops. However, if the numbers of the vector are low, such areas can be kept under continuous surveillance ('inspection project') and control inaugurated as soon as warranted.

The extent of the area over which control measures are necessary depends on the flight range of the vector. Anophelines are usually weak fliers. *A. quadrimaculatus* has an effective flight range approximating one mile, although 80% probably never move more than 1/2 mile from their breeding place. On initiating control it is important to eliminate first all of the breeding places of the vector near the protected area and then work outward until the number of adults reaching the protected population is sufficiently low so that no danger of transmission exists.

After the control program is inaugurated the inspector is responsible for checking at regular intervals all anopheline breeding places

and the results of control operations. These inspections are usually made each week two or three days after an application of larvicide. Findings are recorded at the time of inspection on a field record form, such as MCWA Form M-1 (page 35). These record forms should have space for giving exact location of protected area, date, collector's name, station numbers, notes of special conditions, the last date larvicide was applied, the number of dips taken in each station and the number of anopheline larvae and pupae found. Space is also often provided for making a record of culicine larvae found.

Adult resting places are also inspected each week. These collections are recorded at the time of inspection on a field record form similar to MCWA Form M-2 (page 36). These forms should have space for recording the exact location of the protected area, the date, collector's name, station number, remarks and a record of the anophelines found. In recording the anophelines found it is important to insert a figure for each station inspected. If for some reason a station is not inspected a dash (-) should be recorded but if the inspection is made and no anophelines found a zero (0) should be inserted in the proper place.

The field record forms are submitted at the end of the day to the control supervisor so that immediate use can be made of the data in planning his operations. In breeding areas where larvicide is being regularly applied and only small larvae can be found, effective work is indicated as these will be killed before maturity by the next larvicide application. The finding of large larvae and pupae indicates inefficient control and immediate re-treatment is necessary.

A logical interpretation of the reports illustrated on pages 35 and 36 would be that adequate control is being maintained. These reports show that larvae are not reaching maturity within the control zone and that the counts in the adult stations within 1/4 mile of the protected area (stations 1, 2, 4, and 6) are low. The adult

State Sample LARVAL MOSQUITO COLLECTION—Field Record
 Area 3-Jackson Date July 7, '42 Collector C. Jones Identifier

Notes

STATION NUMBER	LOCATION OR REMARKS Zone 1-Camp Quad	Last Date Larvicide Applied	No. Dips*	ANOPHELES				OTHERS			
				Total	Small	Large	Pupae	quad.	cruc.	punc.	Total
1-A		7/4	10	40	40						25
2-A		7/4	30	0							
3-C		7/4	30	4	4						8
4-B		6/13	30	20	20						10
5-D	Dry	7/4	0								
6-A		6/20	10	25	25						25
7-A		7/4	30	25	25						8
7b-B		7/3	30	0							
8-B	Dry	-	0								
9-C		7/3	30	0							3
10-C		7/3	30	15	15						5
11-E		-	10	50	25	15	10				15

MCWA-101

U. S. P. H. S. Malaria Control in War Areas

FORM
M-1

State Sample ADULT MOSQUITO COLLECTIONS—Field Record
 Area 3 - Jackson Date July 1, '42 Collector C. Jones Identifier C. Jones

Notes

STATION NUMBER	LOCATION OR RELATION	ANOPHELES												CULICINES					
		quad.		citr.		punct.						Total							
		M	F	M	F	M	P	M	P	M	P	N	F						
1-A	Zone 1 - Camp Quad	0										-1							
2-A		1										1							
3-B		3										10							
4-A		0										0							
5-C		8										26							
6-A		1										1							
7-B		5										5							
8-C		10										18	1						
9-D		20										20	8						
10-E		8	45									8	45	215					
11-E		3	30									3	30						
L-T-A												1		10	A. vexans				

U. S. P. H. S. Malaria Control in War Areas

MCWA-102

FORM
M-2

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE—MALARIA CONTROL IN WAR AREAS

WEEKLY ENTOMOLOGICAL REPORT
Sample 3-Jackson 1-Camp Quad July 11 '43
(Site) (Zon.)
(Area)

STATION NO.	ADULT ANOPHELINE ABUNDANCE											
	SPECIAL INDEX "A" STATIONS						HIGHEST STATIONS					
	1-A	2-A	3-A	4-A	5-A	6-A	7-A	8-A	9-B	10-C	11-D	
Quadrinotatus	0	0	0	0	0	0	1	1	0	0	0	0
Anopheles	0	0	0	0	0	0	0	0	0	0	0	0

BREEDING PLACE INSPECTIONS

Total number of ABCD stations: 21

Number inspected 21
Number with *Anopheles* breeding 14

Number with large *Anopheles* larvae and pupae 0

Maximum collection large *Anopheles* larvae and pupae in 10 dips (ABCD Stations)
Have you discussed mosquito records with area supervisor this week?

REMARKS:
dry this week.

(Name) C. Jones
(Title) Treasurer

Type of project (check one):
 Control and inspection
 Inspection only

mosquito densities in the B, C, and D stations represent an infiltration of mosquitoes from outside the area under control, while those at E stations indicate more or less normal mosquito densities for the locality.

When high adult *quadrimaculatus* counts occur in 'A' stations, the field record form (M-1) report should show whether or not it is due to inefficient larvical work. If the M-1 does not record large larvae and pupae, either (1) undiscovered breeding places probably exist which must be searched out and controlled, or (2) unusually long and heavy flights are coming in from outside the control zone.

At the end of each week the data from the field report forms (M-1 and M-2) are consolidated on weekly summary forms such as MCWA M-3 and M-4, for use by State and headquarters offices. These are 8" x 10 $\frac{1}{2}$ " sheets with the same headings as the M-1 and M-2, respectively.

Mosquito specimens not identified in the field are sent at the end of the week to a central laboratory with a copy of the consolidated collection record.

On the Malaria Control in War Areas program where official inquiries are frequent, a system for supplying current information on the status of each project to the headquarters office was necessary. A postal card (M-7) was devised to give selected entomological data from each project for this purpose. This form is prepared each week by the field personnel and mailed directly to the headquarters office.

Form M-7 shows the numbers of the important malaria vectors found in five 'special index A stations' representative of the protected area as a whole. These same stations are reported each week so that a continuous record of the fluctuation of densities will be available. In addition, the highest count of the important malaria vector in any A, B, C, D, or E station is shown on the card to indicate general conditions

in the locality. These latter stations may vary from week to week. Space is also provided on the card for recording other information about anopheline breeding conditions and the status of the project.

ENTOMOLOGICAL FIELD EQUIPMENT

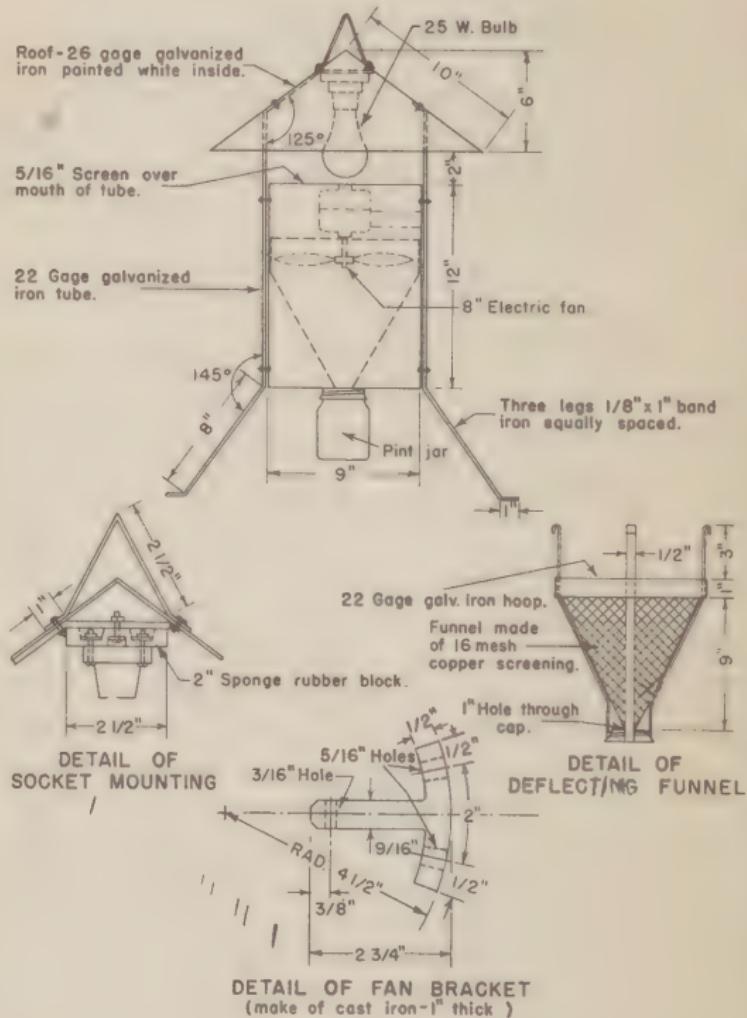
Complete field equipment, properly carried so that it is ready for use, is essential to good field work. Typical equipment is illustrated on page 31.

THE NEW JERSEY LIGHT TRAP

This trap is illustrated on page 40. It consists of a vertical metal cylinder covered by a conical metal roof, under which a 25-watt, 110 volt, white frosted bulb is attached. The light socket is attached through a block of sponge rubber in order that vibrations from the fan will be minimized. Covering the upper end of the vertical cylinder, and below the bulb, is a 5/16" mesh screen which is affixed to screen out the large insects, while permitting mosquitoes and other small insects to be sucked into the tube by an electric fan located inside the tube, below the screen. A funnel-shaped screen of 16 mesh wire fits tightly within the vertical tube below the fan. This funnel directs the catch into a pint Mason jar containing a poisonous chemical. The trap is supported by three metal strips bolted to the vertical tube, which extend below the tube to form legs and above the tube to form support for the conical roof.

The killing jar is usually prepared by placing a half inch layer of calcium cyanide crystals in the bottom of the jar. The chemical is held in place by alternate layers of cardboard and cotton, totaling about one-half inch in thickness; or it may be covered with plaster of paris through which small holes are bored to permit the gas to escape. Cyanide is a deadly poison and great care must be exercised in handling

NEW JERSEY MOSQUITO LIGHT TRAP



it. A perforated wax paper cup may be placed in the mouth of the jar to hold the insects as they drop into the jar and are killed.

HANDLING OF MOSQUITO SPECIMENS (page 42)

PREPARATION OF LARVAE FOR IDENTIFICATION

Temporary mounts for immediate identification may be made by merely mounting the larva in a drop of water on a glass slide.

PRESERVATION OF LARVAE

Larvae may be preserved in 50-70% alcohol or 4-5% formalin.

MOUNTING OF FRESHLY KILLED ADULTS FOR IDENTIFICATION

Mounts with micro-pins and cork may be made, or specimens may be glued to paper triangular points.

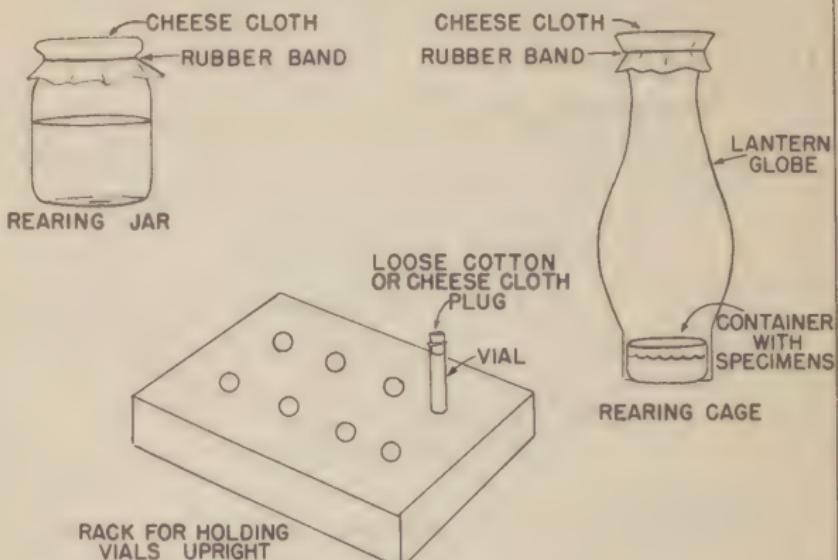
MOUNTING OF DRIED ADULTS FOR IDENTIFICATION

Specimens dead more than twelve hours become brittle. If carefully handled, they may be mounted by the point method. An alternative is to place them in a relaxing jar (page 42) in which specimens again become soft after 24 hours.

REARING OF LARVAE AND PUPAE TO ADULTS

Larger larvae can be reared more satisfactorily than smaller ones. Water from the breeding place is usually used; supplementary food may be needed in the form of a small amount of finely ground dog biscuit if the water is very clear. The pupae are transferred daily by a wide-mouthed pipette or spoon to small jars or vials containing water, covered with loose-fitting cotton plugs or pieces of cheesecloth to prevent the adults from escaping and to serve as a foothold for the newly emerged adults. It is important to keep the breeding containers in a moderately cool place out of direct sunlight. Wide variations in temperature should be avoided. Newly emerged adults should not be killed or mounted for 24 hours.

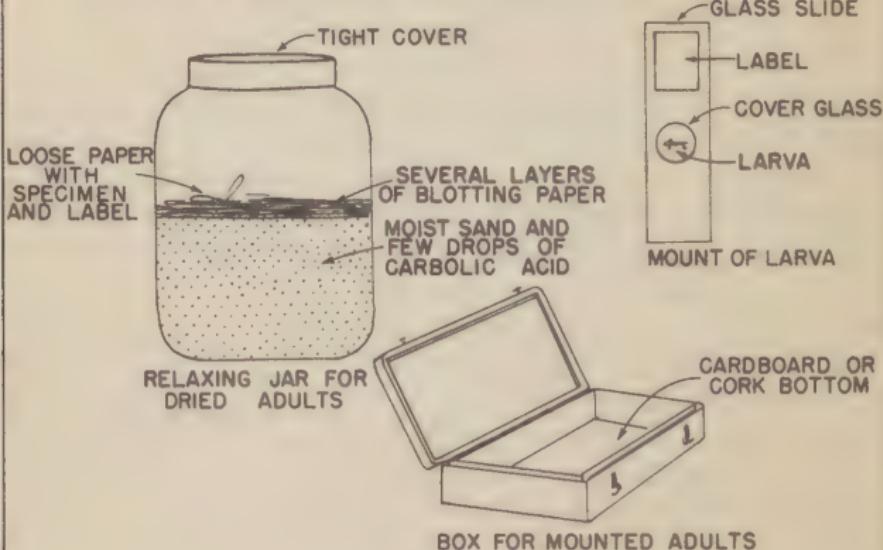
REARING EQUIPMENT



MOUNTING EQUIPMENT



VARIOUS METHODS OF MOUNTING



SHIPPING OF LARVAE

Larvae may be shipped in vials or other containers, always properly labeled. Less damage will occur to specimens if the container is full of preserving fluid. The containers are then packed in newspaper or other protective material in a box or paper tube for mailing. If for official business, a franked label may be used.

SHIPPING OF ADULTS

Adults are shipped in pill boxes, properly labeled in pencil. A very small amount of facial tissue or cotton, so thin that newsprint can be read through it, is placed below the specimens to prevent movement and breakage, but none is placed above the specimens. These pill boxes are then packed and sent in the same manner as the larvae.

STORAGE OF ADULTS

Specimens must be dried before storage or they will mold. They must be stored in a tight container with paradichlorobenzene or moth balls, in order to prevent destruction by museum pests. Specimens left exposed frequently are destroyed by accidents, mice or ants.

CONTROL MEASURES

Detailed consideration will be given to anopheline control methods in other chapters of this manual which are to be issued at a later date. This comprehensive summary of control procedures is included here for the purpose of presenting information of a perspective nature.

A wide variety of anti-mosquito measures may be employed in *Anopheles* control, some of which are those generally employed in anti-mosquito work, others are specific for anophelines, and still others are specific for individual species. Proper corrective technics for any problem should be selected on the basis of the habits of the species which are the malaria carriers. 'Species sanitation' is the term applied when efforts are directed toward control of a single species. This is the objective of the Malaria Control in War Areas program; attention being directed to the important vectors of malaria discussed in previous sections.

Three general types of methods are ordinarily employed for *Anopheles* control. These are:

- I. Eliminating the breeding areas
- II. Poisoning the aquatic stages
- III. Modifying the larval habitat

The destruction of adult mosquitoes, which is an important malaria control measure in some instances, is not regarded as an anopheline control measure, since the actual reduction in numbers of mosquitoes brought about is comparatively insignificant.

ELIMINATING THE BREEDING AREAS

Physical corrective measures used on the MCWA program include filling and drainage projects in both major and minor categories. Following are some of the methods employed in removing *Anopheles* breeding areas.

A. *Filling.* Breeding areas frequently can be eliminated by filling with dirt or various types of rubbish. This offers the best method of treatment. Although filling usually is comparatively expensive it has the advantage of permanency.

The type and size of fill required and the local conditions determine methods to be used and whether hand operations or the use of trucks, scrapers, bulldozers, draglines or hydraulic dredges will be most economical.

B. *Drainage.* Providing outlets for impounded water is the objective of drainage operations. Run-off must be rapid enough to insure removal of water before larvae can mature. Usually, breeding areas are drained into flowing streams or large bodies of water beyond the limit of control operations. In some cases 'sump drainage' may be employed by draining several small aquatic areas into a larger one to reduce the total breeding surface or to otherwise facilitate larvicultural work.

Drained areas and outlet ditches should be regularly inspected for retained water in the original ponded area or for still, ponded places in the drainage ditches and corrective measures should be applied when necessary.

The type of drainage work undertaken will depend on the soil type, rainfall, land contour and other physical conditions. There are four general drainage methods:

1. *Open ditches.* For permanency these may be lined with various types of masonry. Monolithic or precast concrete linings are frequently used. The sodding of banks also is often practiced to prevent erosion.

2. *Subsurface drainage.* Drain-tile, French drains, or covered culverts are types generally used. The use of mole plows for constructing unlined underground drainage systems is sometimes feasible.

3. *Vertical drains.* This system may be used where underground water strata can be intercepted.

4. *Pumping.* Pumping is generally used in conjunction with the above three methods, but occasionally is used alone for dewatering small breeding areas.

Many factors must be considered when undertaking drainage work, including the economics of the project. The effect of removing reservoirs of water used by livestock, the lowering of water-tables below the reach of field crops, the contamination of sub-surface water supplies and many other economic and sanitary problems all must be evaluated.

POISONING THE AQUATIC STAGES

Many larvicides are in use for the destruction of the aquatic stages of anopheline mosquitoes. The larvicide selected and the method of application depends upon the particular problem presented.

- A. *Paris green* (copper acetoarsenite) is one of the most common larvicides employed. It is used as a fine powder diluted with an inert dust such as lime, Fuller's earth, talc or road dust. Paris green is usually applied at the rate of $\frac{1}{2}$ to 1 pound (5 to 10 lbs. of mixed dust) per acre of breeding surface per application. Dilution with inert material is usually in the ratio of 1 part paris green to 9 parts of diluent by weight. This poison must be ingested by the larvae to be effective but very small amounts are toxic. Paris green must be re-applied at approximately

weekly intervals as it has no residual effect. Since this is a gastric poison, the non-feeding pupae are not affected. Few culicine larvae are killed by dusting since they feed below the water surface. Dusts are applied by hand and power equipment and when large areas are involved, airplane dusting can be economically used.

- B. *Larvicidal oils.* The spreading of oil over the breeding surface is effective against most all mosquito larvae and pupae. The oil used should not be highly refined; #2 Diesel oil is satisfactory. Rate of application is about 20 gallons per acre per application. Oils may be applied by a wide variety of hand and power spray equipment. The type selected will depend on the size of the job to be done.
- C. *Other effective larvicides.* These include cresylic acid, phenols, pyrethrum, phenothiazine, copper arsenite and cuprous cyanide. They are used as emulsions, solutions or dusts.

MODIFYING THE LARVAL HABITAT

Various methods of creating conditions adverse to mosquito breeding have been described. Many of these are of doubtful value and they are usually specific for a single or few species. Hence, the application of such methods is very critical and depends upon detailed knowledge of the biology of the particular *Anopheles* species to be controlled.

- A. *Removal of protective vegetation and floatage* is one of the most common methods of control in this category. By mechanically clearing the water surface of vegetation and debris, predators are given free access to the aquatic stages of mosquitoes and the full effect of wave action is gained. Herbicides may be of some value in destroying vegetation.

- B. *Rechanneling* is of some value if more rapid run-off is effected. Ox-bows and temporary sloughs can sometimes be eliminated. The efficiency of this method of control ordinarily depends upon proper maintenance.
- C. *Water level fluctuation* has proven to be an important means of control, especially on large reservoirs. The technics of reservoir management are too detailed to consider here. The primary objectives are to lower the water at intervals to: (1) strand floatage and larvae and (2) bring larvae to open water out of the marginal vegetation where they can be reached by predators and wave action.
- D. *Intermittent drying* is useful where it can be applied. The chief application is in rice fields.
- E. *Change of salinity* is an effective means of control but has little, if any, application in this country. Salt marshes may be flooded with fresh water to make conditions unfavorable for brackish water species; fresh-water breeding areas may be flooded with sea water to create conditions unfavorable for fresh-water species.
- F. *Impounding*. Small slow-flowing bayous may be cleared and impounded at intervals in order to concentrate the water in places accessible for treatment or to maintain conditions suitable for natural control.
- G. *Changes in light* on breeding areas sometimes modifies the mosquito fauna. There is the danger in some places, however, of replacing a comparatively benign species with a more harmful one.
- H. *Flushing* has limited application as a means of *Anopheles* control. Water is released periodically by means of gates or

siphon's. The rush of water flushes the larvae from the channel and in receding leaves them stranded.

I. *Modifications in flora.* This method involves the growing of plants so thickly that the entire water surface is covered thus making conditions under which larvae cannot develop. If the watered area is of any value for commercial or recreational purposes this method is not applicable.

J. *Introduction of top-feeding minnows.* Several species of minnows may be introduced into breeding areas to assist in mosquito control. *Gambusia affinis* is the species most adaptable in this country.

Of the large number of plants (*Chara*, Bladder Wort, Smart Weed, etc.) which at one time or another have been credited with having larvicultural qualities, none have been proven of value in practical control operations.

ADULT DESTRUCTION

Adult *Anopheles* destruction is a malaria control measure which is applicable chiefly during malaria epidemics or in regular malaria control work when the number of people to be protected is small or where such overwhelmingly large breeding areas occur that other means of control are not practical. It is primarily adapted for use against the highly domesticated anophelines which seek daytime resting places in and about human habitations. In the case of malaria epidemics, adult mosquitoes in and about habitations are given first attention as they are the ones which will become infected and transmit malaria. The value of adult destruction as a general mosquito control measure has not been determined.

The following methods are used in adult destruction:

A. *Spraying.* This is the most effective

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method of killing adult mosquitoes. Kerosene extracts of pyrethrum flowers are the most satisfactory insecticides for this purpose at present, although many effective synthetic compounds are on the market. The new aerosol sprays which are being used by the armed forces promise to revolutionize present methods of spraying.

- B. *Hand killing* by the use of fly swatters has been used with good results when faithfully practiced. This is a poor substitute, however, for spraying.
- C. *Mosquito traps* are of little, if any, value in control. They are for index work.
- D. *Natural predators of adults.* Predators are of great value in maintaining the biological balance in nature. Birds, bats, dragonflies, etc., destroy myriads of mosquitoes. However, no method for colonizing these in order to give worthwhile protection in any area has been devised.

Other methods of malaria control which cannot be considered as mosquito control measures are:

- 1. Protection of people from bites of mosquitoes by mosquito proofing houses and centers of congregation.
- 2. Use of repellents to prevent bites.
- 3. Use of fans and wind currents to keep mosquitoes away.
- 4. Employment of animal barriers to deflect mosquitoes from the human population.
- 5. Removal of populations to areas where malaria transmission cannot occur naturally.
- 6. Use of prophylactic drugs.

*
THE MORE IMPORTANT MALARIA VECTORS OF THE WORLD

BREEDING PLACE	SPECIES	DISTRIBUTION	CONTROL MEASURES
I.	<i>a. albimanus</i>	Mexico, So. Texas, Cen. America, West Indies Southern Europe and Eastern Europe and Russia	Increase salt content of water by flooding with sea water, or decrease salt content by flooding with fresh water. Natural or artificial fill. Open marsh ditching. Dykes, tide gates and drains. Oiling. Paris green.
	<i>sacharovi</i>	Near East and extreme northwest India	
	<i>I. labranchiae</i>	Southern Europe	
	<i>I. atroparvus</i>	Spain, Portugal	
	<i>sundaicus</i>	Bengal	
	<i>p. moluccensis</i>	Burma, Thailand, Indo-China, Andaman Islands Malaya	
		Netherlands East Indies	Drainage. Natural or artificial fill.
		So. Pacific Islands	Enclosure by dykes,
III.	<i>a. albimanus</i>	Fresh-water swamps and weed-grown waters, usually	

BREEDING PLACE

DISTRIBUTION

CONTROL MEASURES

SPECIES			
<i>open to sun-</i> <i>light.</i>	<i>albimanus</i> South America	with constant level flooding plus larvi- cidal fish. Pollution and packing with decay- ing vegetation. Larvi- cidal fish. Shading. Paris green. Oiling. Pyrethrum larvicide.	
	<i>albitarsus</i> South America		
	<i>sacharovi</i> Southern Europe		
	<i>Eastern Europe and</i> <i>Russia</i>		
	<i>Near East and extreme</i> <i>northwest India</i>		
	<i>messeae</i> <i>m. maculipennis</i>	<i>Eastern Europe & Russia</i>	Drainage. Natural or artificial fill. Clear- ing to let in sunlight.
	<i>p. punctulatus</i>	<i>Eastern Europe & Russia</i>	Pollution and packing with decaying vegeta- tion. Paris green.
	<i>p. moluccensis</i>	<i>So. Pacific Islands</i>	Oiling. Pyrethrum lar- vicide. Larvicultural fish.
	<i>umbrosus</i>	<i>Malaya, Netherlands</i>	
	<i>leucosphyros</i>	<i>East Indies</i>	
		<i>Burma, Thailand, Indo-</i>	
		<i>China, Borneo.</i>	
III.	<i>Fresh water swamps,</i> <i>pools, stream beds,</i> <i>etc., under forest,</i> <i>jungle or dense</i> <i>shade.</i>		

BREEDING PLACE

DISTRIBUTION

CONTROL MEASURES

IV. Large rivers with their associated pools and seepages

pseudopunctipennis darwini
superpictus

Argentina, Chile, Peru
No. "South America
Southern Europe
Eastern Europe & Russia
Near East and extreme northwest India
Central and South Africa
Central and South Africa

Channelizing stream bed. Controlled silting of stream bed sides. Clear away or poison grass. Larvical fish. Paris green. Oiling. Pyrethrum larvicides. Large scale flushing in some cases.

West, North and Central India
South India
Ceylon
So. Pacific Islands

culicifacies

p. moluccensis

V. Irrigation channels, ditches, and small, sluggish streams.

funestus

superpictus

culicifacies

Channel lining. keep sides and bottom clear of vegetation and obstructions. Rank training. Flushing. Dense shading. Larvical

PREEDING PLACE

DISTRIBUTION

CONTROL MEASURES

SPECIES	PREEDING PLACE	DISTRIBUTION	CONTROL MEASURES
<i>mimetus</i>	Burma, Thailand, Indo-China, South China	Purma, Thailand, Indo-China, So. Pacific Islands	Pyrethrum larvae. Paris green.
<i>aconitus</i>	Burma, Thailand, Indo-China	Burma, Thailand, Indo-China	Oiling.
<i>P. moluccensis</i>	Hill and mountain streams, with associated pools and seepages (above 2000' elevation).	Southern Europe Northeast India Assam Philippine Islands South India Malaya	Flushing, automatic or hand operated Shading. Channelizing stream bed. Larvicidal fish. Continuous drip oiling. Oiling. Paris green. Pyrethrum larvicide.
<i>P. moluccensis</i>	Margins and shallows of reservoirs, ponds, lakes, lagoons and bayous.	So., Central North America South America Northeast India Assam	Clear reservoir bottom of all vegetation before filling. Clear vegetation and floatage from banks. Fluctuating water levels.
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BREEDING PLACE

DISTRIBUTION

CONTROL MEASURES

SPECIES

VIII. Shallow seepages from irrigation, springs, overflows, etc., usually in sunlight.

maculipennis
freeborni

Western No. America

m. maculipennis

Eastern Europe and Russia

Larvicidal fish. Apply paris green or oil by airplane or from boats. Copper sulphate to minimize algae.

Restriction of excessive use of irrigation water canal or ditch lining, or piping, to reduce seepage. Pump out low areas and return water to irrigation canal or drain. Drainage, open, sub-soil, or vertical. Larvicidal fish. Paris green. Pyrethrum larvicide. Oiling.

Central and South Africa

BREEDING PLACE

SPECIES

CONTROL MEASURES

*minimus*rain water pools
in borrow pits,
excavations, wheel
ruts, wallows, etc.

IX.
I. labranchiae
 rain water pools
in borrow pits,
excavations, wheel
ruts, wallows, etc.

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*fluvialis*rain water pools
in borrow pits,
excavations, wheel
ruts, wallows, etc.

I. labranchiae
I. punctulatus
I. moluccensis

X. Rice Fields

rice fields

Open drainage. Sub-
soil drainage. Verti-
cal drainage. Filling.
Pollution and packing
with decaying vegeta-
tion. Oiling. Pyrethrum
larvicides. Paris
green. Cresylic acid
larvicide.

Carefully level paddies
before planting. Keep
banks free from vege-
tation. Usually shade
ditches and drains.
Larvicultural fish. Inter-
mittent drying of
paddies. Muddying water.

BREEDING PLACE

DISTRIBUTION

CONTROL MEASURES

Fyrethrum larvicide.
Paris green. Oiled
sawdust.

XI. Wells *culicifacies umbrosus*

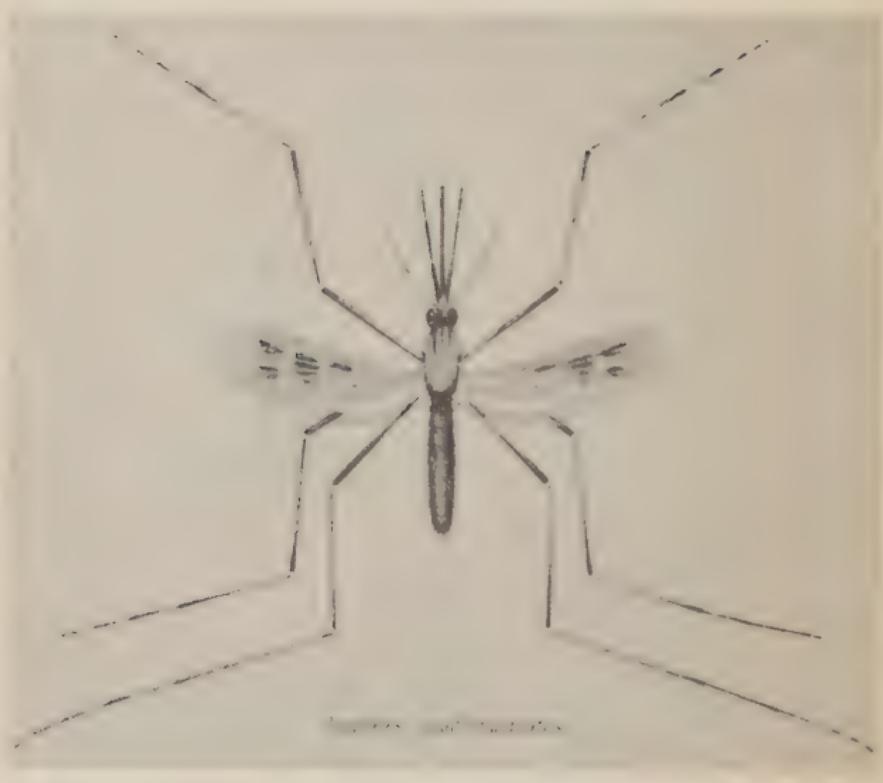
South India
Malaya

Mosquito-proof covering, or screens. Fill abandoned wells. Fyrethrum sprays. Kerosene. Open, shallow wells may be treated as pools.

XII. Cisterns, covered water storage tanks,
etc.

West, North and
Central India

Mosquito-proof covering or screens. Frequent change of water, with surface disturbance. Larvicultural fish. Pyrethrum sprays. Kerosene.



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